Reconstruction of 3-D Shape and Texture by Active Rangefinding

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Abstract

In this paper, a method for active rangefinding system that measures 3-D objects and reconstruct them as models with shape and color is discussed. The rangefinder "Cubicscope" utilized here takes range images together with color images within fractions of a second. It is installed at the tip of a robot manipulator and captures range images from various viewpoints. The 3-D shape reconstruction was made by integrating range images in the measurement space. In order to search the next best viewpoint to observe unmeasured areas on the object surface, jump edges are detected, because there must exist unmeasured area between jump edges on the integrated object surface. This follows the texture mapping from color intensity images onto the object surface which provides high-quality realistic 3-D models for the computer graphic applications. In this paper some experimental results are also represented.

1. Introduction

Active vision strategy must be effectively applied when there exist ambiguities for recognizing 3-D object using a 2-D image taken from an arbitrary viewpoint. Multiple viewpoint images would reduce such ambiguities on 3-D shapes. Even if we obtain several images, however, there still remains a problem, i.e., how to reconstruct or extract 3-D shape information from such intensity images. A practical way to solve this problem is to use a rangefinder that directly grabs 2 1/2-D range images. Each pixel value of the range image indicates absolute distance from the camera to a corresponding point on the object surface. Therefore, the range image contains direct shape information about the object. Of course, ambiguities about 3-D shapes cannot be clarified completely, since the range image only indicates visible surface from the rangefinder. However, the active rangefinding, multiple range image grabbing by selecting the viewpoints adaptively to the object shape, will drastically reduce ambiguities in 3-D shapes.

If we need entire information surface for the object, we have to take range images from multiple viewpoints. Some methods have been proposed for measuring 3-D shapes such as using a turntable for rotating the object relatively to the rangefinder[1][2]. If the shape of the object is simple, these methods can be effectively applied because integrating the captured multiple range image reconstructs entire object surface. However, if the shape of the object is not so simple, because trivially selected viewpoints

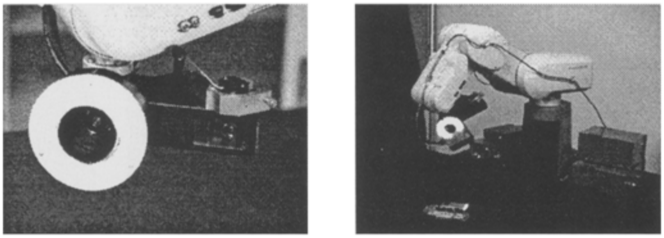


Fig. 1 Cubicscope

cannot compensate surface entirely. A fundamental solution to this is to measure the object from adaptively selected viewpoints to the object shape using a robot manipulator.

The 3-D shape may be reconstructed by integrating range images taken from various viewpoints in the 3-D space. Furthermore, if the rangefinder grabs color images together with the range images, mapping them onto the integrated object surface allows the model reconstruction with shape and color in the computer. Such model can be used in the computer graphics as a real 3-D model for graphics generation. In this paper, we describe a strategy for active rangefinding and reconstructing 3-D models.

2. Handy Rangefinder "Cubicscope"

To obtain range images, we use a rangefinder "Cubicscope"[3] shown in Fig.1(a). The Cubicscope involves a semiconductor laser, a galvano mirror, and a color CCD camera. The method for rangefinding is based on the space encoding method. In this method, the space is divided into some wedge-regions, which is encoded by the intensity sequence of projected stripe pattern. To form the stripe patterns, the beam of the semiconductor laser is expanded vertically to form a slit-ray, and it is scanned horizontally by the galvano mirror. These stripe patterns are captured by the CCD camera. High density range images (512 x 256 pixels) are obtained continuously within 0.3 seconds with 1% accuracy.

3. 3-D Shape Reconstruction Using Range Images

If the viewpoint and direction in the world coordinate system is previously calibrated, our rangefinder can uniquely specify the spatial coordinates of measured points on the object surface. Using a robot manipulator, we can accurately control the rangefinder in the 3-D measurement space to take range images from arbitrary viewpoints. Fig.1(b) shows an active rangefinding system that equips the Cubicscope.

The Cubicscope used here installs a color CCD camera, and a supplemental ring-light is equipped in order to take intensity color images. Using a single camera makes the matching simple between ranges and intensities for each pixel.

Projecting the ranges into the measurement space for ever pixel, we can reconstruct

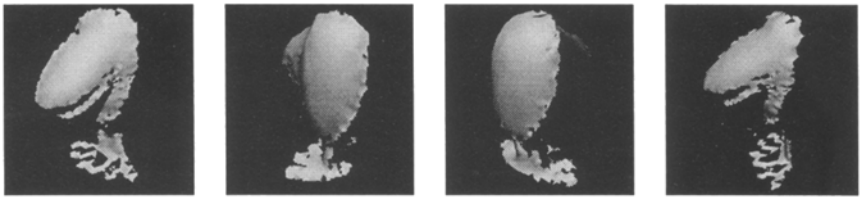


Fig. 2 Range images obtained from some viewpoints

Fig. 3 Integrated object surfaces

Fig. 4 Texture mapped object model

object surface which is visible to the rangefinder. Therefore, the integration of multiple range images taken form various viewpoints using the active rangefinder provides the reconstruction of entire 3-D object shape[3]. Fig.2 indicates the object surfaces obtained from some viewpoints. Fig.3 shows the integration result of the measured surfaces in the 3-D space, with colors in Fig.4.

The range data involve some errors in the measurement due to the mechanical manipulator control, calibration, or rangefinder itself. The surface fittings for the measured surfaces must be useful to reduce the reconstruction error. So far, our method does not apply such a fitting strategy, but averaging the measured points where the multiple surfaces are overlapping allows practical integration results.

4.Adaptive Viewpoint Selection

One of the major tasks in such active rangefinding strategy is how to select the next preferable viewpoint and how to determine the end of the measurement[4]. If the active rangefinding system does not select the viewpoints adaptively to the object shape, some unmeasured surfaces might be remained for complicated objects, otherwise a lot

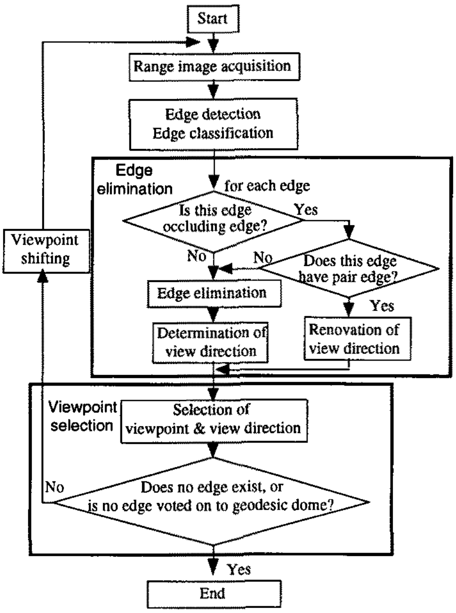


Fig. 5 Flow chart for viewpoint selection

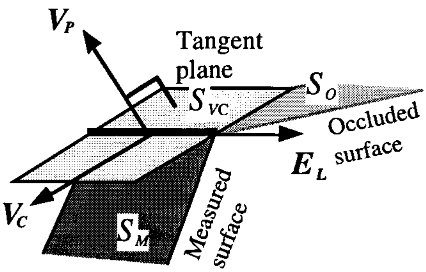


Fig. 6 Next measurement direction

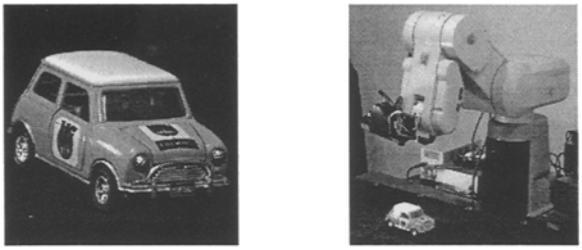
of redundant range images should be taken from slightly sifted several viewpoints.

A hint to resolve such viewpoint selection problem is found in the continuity property for 3-D object surface. A 3-D object is covered by a closed surface that does not include any holes or intersections. Then, the integration of range data never contains any edges if the object has been completely measured. In our viewpoint selection strategy, the vision system tries to search jump edges on the integrated surface. If there exist any of them, it shifts the viewpoint to observe the gap between such surface edges because there still remained unmeasured area there. Fig.5 shows the measurement flow chart for our active rangefinding.

The next preferable view direction should be selected to measure the jump edges. To do so, we determine the view direction as a normal vector of a tangent plane at a jump edge, shown in Fig.6. In practice, however, in practice, it is necessary to determine one of the most preferable viewpoints for many jump edges.

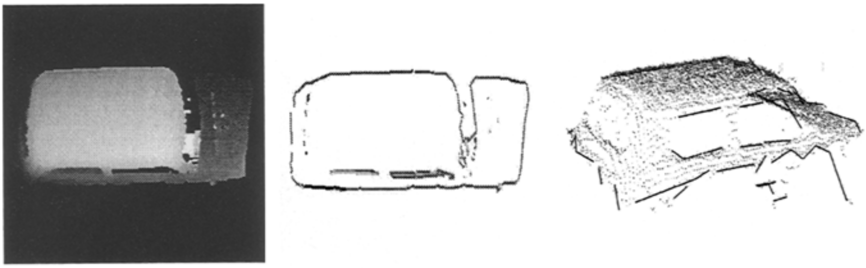
We define a geodesic dome, which is made by subdividing the equilateral triangles of the regular icosahedron, and choose the candidate viewpoint at the triangle centers. We vote to such triangles propotional to the lengths of jump edges, and select the next preferable viewpoint by electing the most voted triangle.

This viewpoint selection is going on adaptively to the 3-D object shape. The active rangefinder moves to choose the next preferable viewpoint in order to observe any unmeasured surface. The measurement terminates if there exist no jump edges found on the measured object surface except occluded area that cannot be measured from any possible viewpoints.



(a) (b)

Fig. 7 Object (a toy car) and measurement system



(a) Range image (b) Edge detection (c) 3-D expression of range data

Fig. 8 First measurement

5.Experimental results

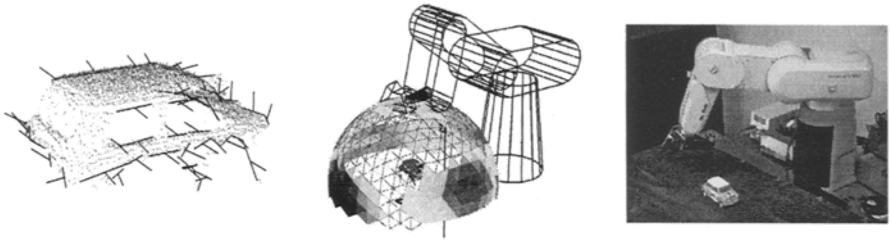
Fig.7(a) shows an object (toy car) and a measurement system. Fig.8(a) shows a result of measured object from the viewpoint on the top, and Fig.8(b) shows a extracted jump edges. The jump edges are approximated with the line segments. Fig.8(c) shows the range data and edge boundaries in the 3-D space.

Fig.9(a) shows the vectors of view direction for each jump edges, and Fig.9(b) shows a generated geodesic dome by these vectors. The more the number of voted vector becomes, the darker the triangle on the geodesic dome. The next viewpoint is selected to the most voted triangle (Fig.9(c)).

The measurement terminates after measuring from 11 viewpoints shown in Fig.10(a); the balls indicate the selected viewpoints, and the lines of the ball describes the view direction. The final measuring results for the object are shown in Fig.10(b) ,with colors in Fig.10(c).

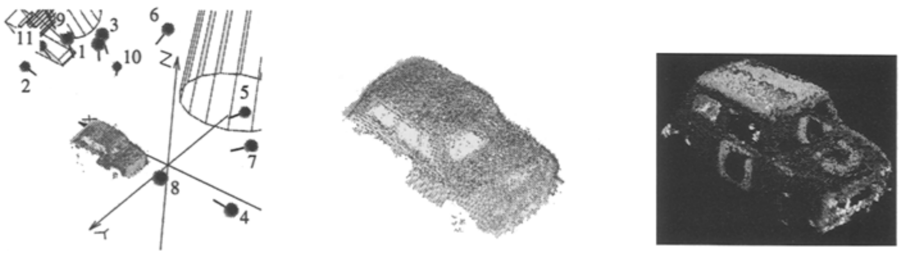
6.Conclusion

This paper has described a method for active rangefinding that takes range and color images from adaptively selected viewpoints. The system automatically seeks the



(a) View direction for each jump edges (b) Geodesic dome for second view direction (c) Result of viewpoint shifting

Fig. 9 Second viewpoint determination



(a) 11 viewpoints and view direction (b) Result of all measurement (c) With color data

Fig. 10 End of the measurement

next best viewpoint extracting edge boundaries in the integrated object surface. Using this proposed method, the next viewpoint is determined very quickly, without guessing the shape of unmeasured surface. And we have shown the result of integrated range data from them, and reconstructing 3-D models with shape and color. This provides high-quality realistic 3-D models for the computer graphics.

Reference

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